2.20 ANTENNA GAIN

The antenna is the last (first) physical device in the transmitter (receiver) component of a radar system. Upon transmission, its purpose is to act as the transducer that converts electrical power to electromagnetic power, enabling the signal to traverse free space. The antenna performs the opposite function when used as a receiving radar system. For a radar used in air defense, there are directions in which the power radiated (or received) is greater than the isotropic level, and there are other directions in which it is less. This phenomenon is described in terms of antenna gain. Antenna gain in any given direction is the ratio of the radiated power density in that direction to the isotropic power density.

Antenna gain may be either directive gain or power gain. Power gain accounts for antenna losses, while directive gain does not. Power gain can be written as a radiation efficiency factor times the directive gain. This factor takes values between 0 and 1. Power gain is customarily assumed in radar equations, but directive gain may be used if the transmitted power is defined appropriately.

The antenna gain in the direction of maximum radiation is often referred to as “the gain” of the antenna, but gain is more properly regarded as a variable function of angular direction. This function defines the radiation pattern of the antenna. Maximum gain may also be called boresight gain or beam axis gain. This maximum gain is generally an input to a radar simulation, and gains in other directions are calculated from it. Frequently, the antenna pattern is used to compute “gain” that has been “normalized” relative to the maximum gain; i.e., the “normalized gain” in a given direction is a fraction to be multiplied times the boresight gain in order to obtain the actual gain in that direction.

In RADGUNS, the antenna pattern is defined in terms of the lobe structure of a radially symmetric beam. Beam lobes are defined in terms of local minima; the main lobe extends from the maximum at the beam axis to the first local minimum; the first sidelobe extends from the first to the second local minimum, and the second sidelobe extends from the second to the third local minimum. The intent of the Antenna Gain FE in RADGUNS is to simulate the antenna pattern of the applicable radar system and use this pattern to determine the gain in any given direction.

2.20.1 Functional Element Design Requirements

This section presents the design requirements for the Antenna Gain FE in RADGUNS for the applicable radar system.

1. The antenna pattern will be modeled as radially symmetric with one mainlobe and a first and second sidelobe.
2. For an off-axis angle θ, the gains in the mainlobe and two sidelobes will be individually modeled as functions of the form $G_{max} \sin(f(\theta))/f(\theta)$, where G_{max} is the maximum gain of the antenna.

2.20.2 Functional Element Design Approach

This section contains descriptions of logic and algorithms used to implement the requirements of Section 2.20.1. The two design elements for the FE characterize the antenna pattern of the applicable system, which has a mainlobe and two sidelobes, each with a gain profile approximated by a function of the form $G_{max}\sin(f(\theta))/f(\theta)$ (Reference 5, Appendix M). Lobe angular span and gain data are specified in Reference 5, pages 20-22, and Appendix M.

Design Element 20-1: Antenna Gain Off-Axis Angle Dependence

The mainlobe and sidelobes of the applicable radar system's antenna gain pattern are assumed to have a constant structure; i.e., a far-field condition is assumed. Thus, the lobes reside in well-defined spans of off-axis angles (the axis is the reference boresight axis at zero degrees). Different functions are used to calculate antenna gain in different lobes, so the first step is to determine which lobe contains the off-boresight angle in the direction of interest.

If $0 \leq \theta < A_1$, then θ is in the mainlobe [2.20-1]
If $A_1 \leq \theta < A_2$, then θ is in the first sidelobe
If $A_2 \leq \theta < A_3$, then θ is in the second sidelobe
If $\theta \geq A_3$, then θ is in the region of constant gain beyond the second sidelobe

where:
A_1 = outer limit of the mainlobe (rad)
A_2 = outer limit of the first sidelobe (rad)
A_3 = outer limit of the second sidelobe (rad)

A_1, A_2, and A_3 are parameters set in the RADGUNS code, based on Reference 5.

Design Element 20-2: Lobe Gain Functions

Each lobe's gain profile is a function of the off-axis angle. Gain for any off-axis angle θ is calculated in two steps. First, a normalized gain $G_n(\theta)$ is calculated. Normalized gain is a fraction between zero and one; i.e., the boresight gain is normalized to the value of one and all other normalized gains are scaled accordingly. This normalized gain is then multiplied by the maximum gain of the radar to obtain the actual gain for any angle. The following function characterizes normalized gain in all lobes:

$$G_N(\theta) = k_1\left(\frac{\sin(k_2(\theta - k_3))}{k_2(\theta - k_3)}\right)^2$$

if θ is within one of the lobes [2.20-2]

where:
θ = off-axis angle (rad)
k_1 = maximum normalized gain value of the lobe
k_2 = empirical constant to scale the lobe half-power beamwidth
k_3 = offset of the center of the lobe from the axis (rad)

The constants k_1, k_2, and k_3 are based on Reference 5.

Beyond the second sidelobe, normalized gain is constant.

$$G_N(\theta) = C \text{ if } \theta \geq A_3 \qquad [2.20\text{-}3]$$

Calculation of the actual gain is then accomplished by a simple multiplication.

$$G(\theta) = G_{max} \quad G_N(\theta) \qquad [2.20\text{-}4]$$

where: $G(\theta)$ = gain for off-axis angle θ
G_{max} = maximum gain of radar

2.20.3 Functional Element Software Design

This section describes the software design in RADGUNS which implements the Antenna Gain FE requirements and design approach. It is organized as follows: the first part describes the subroutine hierarchy and gives descriptions of the relevant subroutines; the next part contains a logical flow chart and describes important operations represented by each block in the chart; the last part contains a description of all input and output data for the functional element as a whole and for each subroutine that implements antenna gain for the applicable system.

Antenna Gain Subroutine Design

RADGUNS uses Subroutine ANTTRK to calculate normalized antenna gain for the subject system. Subroutines ANT01, ANT02, …, ANT07 calculate normalized gain for other systems; these modules will not be discussed. Normalized gain is a term used to describe a fraction that will be multiplied by the maximum gain of the radar to obtain the gain in a given direction. This multiplication takes place in one of four subroutines, depending on the source of the received signal.

The final calculation of gain to be used in determining target signal takes place in RDREQA during acquisition mode and RDREQT during track mode. CLUTG performs this final calculation of gain for a clutter signal and SIGJAM does this for a jamming signal.

The RADGUNS program main routine is called AAASIM. Figure 2.20-1 shows the call hierarchy associated with the Antenna Gain FE. The shaded blocks in the hierarchy denote the modules that directly implement the FE. Table 2.20-1 contains a brief description of each of these subroutines.

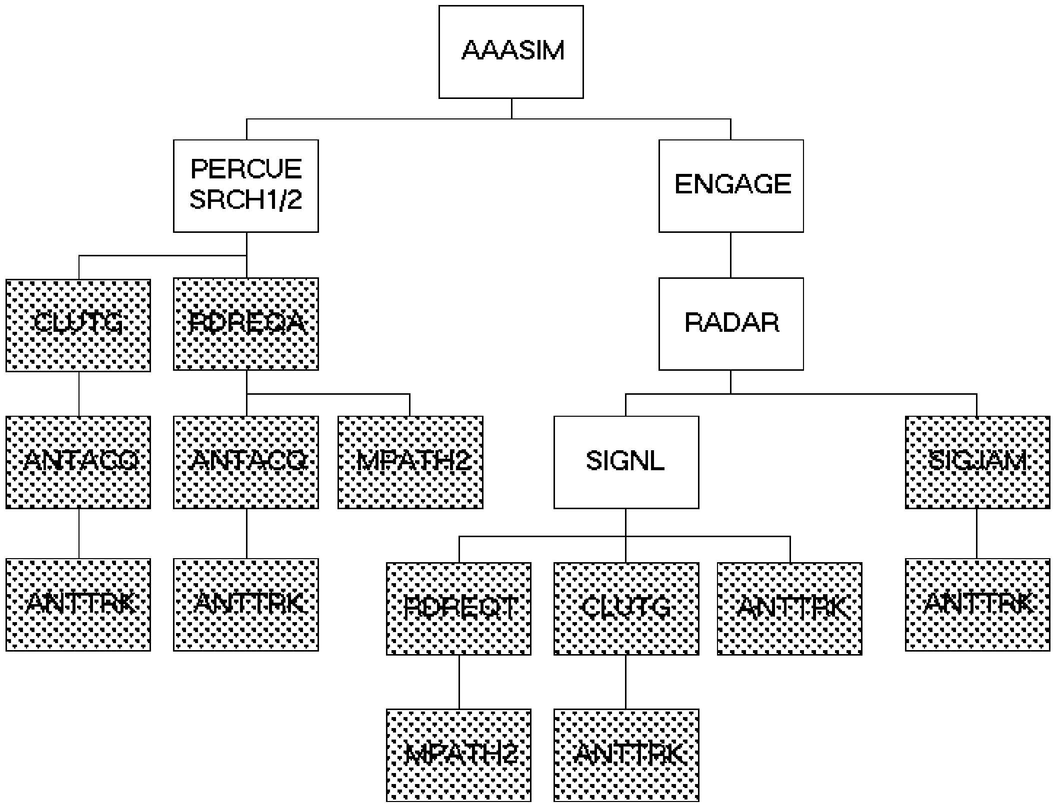

FIGURE 2.20-1. Subroutine Call Hierarchy

TABLE 2.20-1. Subroutine Descriptions.

MODULE NAME	DESCRIPTION
AAASIM	Main routine to simulate AAA system
ANTACQ	Calculates normalized antenna gain in direction of applicable object, acquisition mode
ANTTRK	Calculates normalized antenna gain in direction of applicable object, tracking mode
CLUTG	Computes the power received from a surface clutter patch
ENGAGE	Simulates AAA system while tracking and engaging a target
MPATH2	Computes a multipath factor which accounts for non-direct (path) target returns
PERCUE	Searches for target with antenna cued to target position
SRCH1	Searches for target in sector search or slow circular scan mode
SRCH2	Searches for target in circular scan mode
RADAR	Controls multiple functions associated with the AAA radar
RDREQA	Computes the power received from a target during acquisition mode
RDREQT	Computes the power received from a target during tracking mode
SIGJAM	Determines the power received from each active jammer
SIGNL	Determines the target and surface clutter returns during tracking mode
Note: The modules implementing the Antenna Gain Functional Element are identified in bold letters	

Functional Flow Diagram

Figure 2.20-2 depicts the logic flow of the Antenna Gain FE for the subject system; the FE is implemented primarily by Subroutine ANTTRK. Variable names are enclosed in parentheses. The blocks are numbered for ease of reference in the following discussion.

Blocks 1 through 7 are implemented in Subroutine ANTTRK. Block 8 is implemented in Subroutine RDREQA, RDREQT, CLUTG, or SIGJAM, depending on the type of signal being calculated.

Block 1. Local variable data initialization occurs during the first call to Subroutine ANTTRK for the simulation run. The data characterize lobe beamwidths, maximum values, and off-axis angles that bound the lobes; these will be identified in the block explanations below.

Block 2. The absolute value of the off-axis angle is computed, because the antenna pattern is assumed to be radially symmetrical. This angle is stored in variable THETA.

Blocks three through six represent four branches of an IF-THEN block which determines the normalized antenna gain based on the angle calculated in Block 2.

Block 3. A check is performed to determine if the off-axis angle is within the bounds of the mainlobe. The algorithm is described by equation (2.20-1), with A_1 (lobe maximum angle value) implemented by variable ALOBE1. If the check is positive, the normalized gain is calculated using Equation (2.20-2), with k_1 (lobe maximum normalized gain value) equal to one, k_2 (lobe beamwidth factor) implemented by variable C1, and k_3 (lobe offset from the axis) equal to zero for the mainlobe.

Block 4. A check is performed to determine if the off-axis angle is within the bounds of the first sidelobe. The algorithm is described by equation (2.20-1), with A_2 (lobe maximum angle value) implemented by variable ALOBE2. If the check is positive, the normalized gain is calculated using equation (2.20-2), with k_1 (lobe maximum normalized gain value) implemented by variable C4, k_2 (lobe beamwidth factor) implemented by variable C3, and k_3 (lobe offset from the axis) implemented by variable C2.

Block 5. A check is performed to determine if the off-axis angle is within the bounds of the second sidelobe. The algorithm is described by equation (2.20-1), with A_3 (lobe maximum angle value) implemented by variable ALOBE3. If the check is positive, the normalized gain is calculated using equation (2.20-2), with k_1 (lobe maximum normalized gain value) implemented by variable C6, k_2 (lobe beamwidth factor) implemented by variable C1, and k_3 (lobe offset from the axis) implemented by variable C5.

Block 6. If the off-axis angle is greater than or equal to the maximum angle of the second sidelobe, the gain is set to a constant value. The algorithm is described by equation (2.20-3), with A_3 (lobe maximum angle value) implemented by variable ALOBE3. The algorithm is implemented by a default execution branch when the (former) checks are negative for an off-axis angle residing within one of the lobes. The normalized gain value is implemented by variable C7.

Block 7. A check is performed to determine if the normalized gain value to be passed to the calling routine is less than a minimum; the minimum value is the constant value defined by variable C7 (also used in Block 6). If the normalized gain is less than C7, it is set equal to C7.

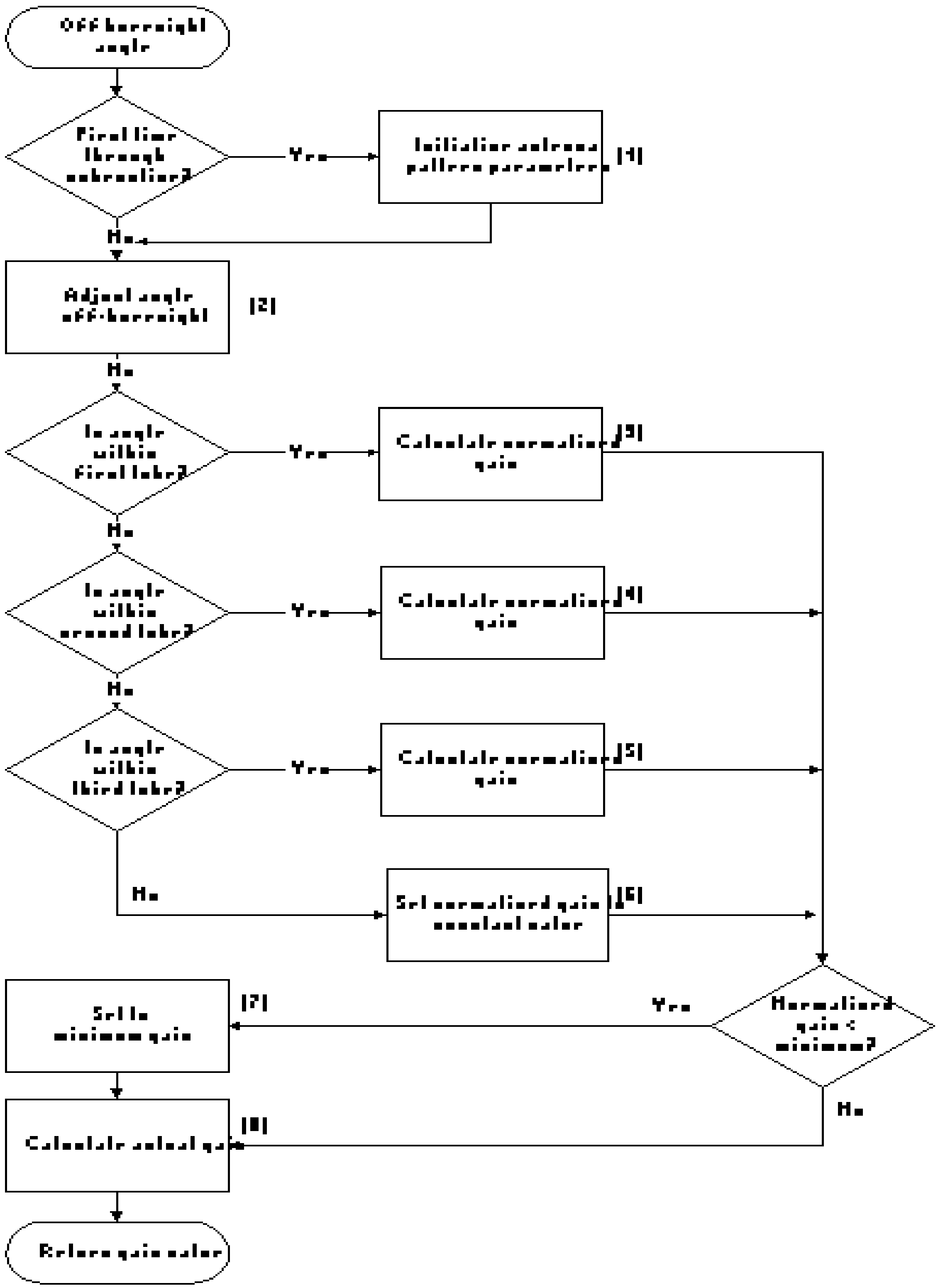

FIGURE 2.20-2. Antenna Gain FE Flow Diagram.

Block 8. The normalized gain is multiplied by the maximum gain of the radar to obtain the actual gain in the desired direction as described by equation (2.20-4). This is done as part of the calculation of signal power of the target, including multipath contributions. Actual gain is calculated in Subroutine RDREQA during acquisition mode, and RDREQT during track mode. The actual gain in the direction of ground clutter is calculated in CLUTG, and the actual gain in the direction of jammer(s) is implemented by SIGJAM. The multiplication is not implemented directly; it is performed as part of a series of calculations in the signal computations.

Antenna Gain Inputs and Outputs

Table 2.20-2 identifies the output of the Antenna Gain FE. Table 2.20-3 identifies subroutine local variables that implement the FE. This FE encompasses a radar system function which is not directly affected by user input for the applicable system; but, several variables have hard-coded values as input to this FE. Table 2.20-4 describes these hard-coded variables and lists the module in which each variable is set. Tables 2.20-5 through 2.20-10 describe the inputs and outputs of all modules that implement the Antenna Gain FE; variables listed in bold letters denote those which are directly related to this FE.

TABLE 2.20-2. Functional Element Output.

NAME	DESCRIPTION
ANTTRK-GANT	Antenna gain in the direction of interest. Note: This multiplication is not implemented directly, but is implemented in Subroutines RDREQA, RDREQT, CLUTG, and SIGJAM.

TABLE 2.20-3. Local Variables Included in FE.

VARIABLE NAME	MODULE	DESCRIPTION
ANTENA	CLUTG	Normalized antenna gain in direction of ground clutter patch
FACTOR	RDREQA	Intermediate calculation of the power of the target return signal without multipath contribution
FMPATH	RDREQA, RDREQT, MPATH2	Stores the Function value returned by MPATH2
GMPATH	RDREQA	Normalized antenna gain in direction of multipath reflection
GTARG	RDREQA, SIGJAM	Normalized antenna gain in direction of the target
TEMP1	MPATH2	Intermediate calculation for calculating variable FMPATH
TEMP2	MPATH2	Intermediate calculation for calculating variable FMPATH

TABLE 2.20-4. Hard-Coded Inputs to FE.

VARIABLE NAME	MODULE	DESCRIPTION
ALOBE1	ANTTRK	Off-axis angle, outer edge of mainlobe (rad)
ALOBE2	ANTTRK	Off-axis angle, outer edge of first sidelobe (rad)
ALOBE3	ANTTRK	Off-axis angle, outer edge of second sidelobe (rad)
C1	ANTTRK	Empirical constant which determines the beamwidth of the mainlobe and second sidelobe
C2	ANTTRK	Offset angle between the axis and the center of the first sidelobe (rad)
C3	ANTTRK	Empirical constant which determines the beamwidth of the first sidelobe
C4	ANTTRK	Fraction of maximum gain of the first sidelobe
C5	ANTTRK	Offset angle between the axis and the center of the second sidelobe (rad)
C6	ANTTRK	Fraction of maximum gain of the second sidelobe
C7	ANTTRK	Constant gain value for off-axis angles greater than or equal to the maximum angle of the second sidelobe
EPS	ANTTRK	Small number used to prevent a division by zero error
GANT	RDRDAT	Maximum gain of the radar system

TABLE 2.20-5. Subroutine ANTTRK Inputs and Outputs.

SUBROUTINE: ANTTRK					
INPUTS			OUTPUTS		
NAME	TYPE	DESCRIPTION	NAME	TYPE	DESCRIPTION
ANGLE	Argument	Angle between antenna boresight and direction of interest (rad)	ANTTRK	Function	Antenna gain in the direction of the target of interest
ELMTI	Common	Target elevation angle for dynamic MTI on-off switching (rad)			
FIRST	Common	Logical variable, causes a local variable initialization for first call to ANTTRK			
RDRSYS	Common	Radar system designator			

TABLE 2.20-6. Subroutine CLUTG Input/Output Variables.

SUBROUTINE: CLUTG					
INPUTS			**OUTPUTS**		
NAME	**TYPE**	**DESCRIPTION**	**NAME**	**TYPE**	**DESCRIPTION**
BMAZ	Argument	Transmit beam azimuth angle (rad)	AVCGLT	Common	Average backscatter coefficient per subroutine execution (m^2/m^2)
BMEL	Argument	Transmit beam elevation angle (rad)	**CLUTG**	Function	Clutter power at receiver (W)
C	Common	Speed of light (m/s)	RHORIZ	Common	Antenna-to-horizon slant range (m)
CLUPAR (1)	Common	Surface backscatter coefficient (m^2/m^2)			
CLUPAR (2)	Common	Surface backscatter variation (m^2/m^2)			
CLUTON	Common	Clutter enable “switch” (on-off)			
CLUTYP	Common	Clutter modeling method, “descriptive” or “numerical”			
ELBW	Common	Half-power elevation beamwidth (rad)			
FIRST	Common	Logical indicating first call to subroutine			
GANT	Common	Radar boresight antenna gain, not normalized			
HANT	Common	Antenna height above ground (m)			
ISEAST	Common	Sea State (1 through 8)			
LNDCVR	Common	Land Cover (1 through 6)			
LNDFRM	Common	Land Form (1 through 5)			
PHIB	Common	Half-power azimuth beamwidth (rad)			
PHICRT	Common	Angle of incidence above which the surface RCS is constant (rad)			
HILLON	Common	Hill definition “switch” (on/off)			
PI	Common	$\pi = 3.14159 \ldots$			
POLRZ	Common	Transmit beam polarization			
PTX	Common	Transmit beam power (W)			
PWIDTH	Common	Transmit beam pulse width (s)			
RE	Common	4/3 earth radius (m)			

TABLE 2.20-6. Subroutine CLUTG Input/Output Variables. (Contd.)

SUBROUTINE: CLUTG					
INPUTS			OUTPUTS		
NAME	TYPE	DESCRIPTION	NAME	TYPE	DESCRIPTION
RDRSYS	Common	Name of radar system			
TERAIN	Common	Type of environment (land or sea)			
TOTLOS	Common	Transmitter system losses			
TWOPI	Common	2π			
WLNTH	Common	Transmit beam wavelength (m)			
WNDASP	Common	Aspect angle of wind (deg)			
RANGE	Argument	Range from radar to clutter patch (m)			

TABLE 2.20-7. Subroutine MPATH2 Input/Output Variables

SUBROUTINE: MPATH2					
INPUTS			OUTPUTS		
NAME	TYPE	DESCRIPTION	NAME	TYPE	DESCRIPTION
COSP2	Argument	Cosine of the multipath phase angle shift, single-bounce path	MPATH2	Function	Multipath correction factor
COS2P2	Argument	Cosine of the multipath phase angle shift, double-bounce path	FMP	Common	Ratio of power received from multipath to power received from direct reflection from target
GMPATH	Argument	Normalized antenna gain in the direction of the multipath reflection point			
GTARG	Argument	Normalized antenna gain in the target direction			
MPPAR(1) MPPAR(2) MPPAR(3)	Common	Multipath near/far surface reflection coefficients, percent variation in reflection			
MPPAR(4)	Common	Ground distance from radar for change from near to far surface reflection zones (m)			
MPTHON	Common	Multipath capability on/off flag			
TARRG	Argument	Slant range from radar to target (m)			

TABLE 2.20-8. Subroutine RDREQA Input/Output Variables.

SUBROUTINE: RDREQA					
INPUTS			**OUTPUTS**		
NAME	**TYPE**	**DESCRIPTION**	**NAME**	**TYPE**	**DESCRIPTION**
BSAZ	Argument	Boresight azimuth (rad)	RDREQA	Function	Acquisition radar signal return power from target, includes multipath (W)
BSEL	Argument	Boresight elevation (rad)			
COSP2	Argument	Cosine of the multipath phase angle shift, single-bounce path			
COS2P2	Argument	Cosine of the multipath phase angle shift, double-bounce path			
ECHO	Common	Radar signal return power from target, no multipath contributions (W)			
GANT	Common	Radar boresight antenna gain, not normalized			
PI	Common	π (3.14159265359)			
PTX	Common	Radar transmit power (W)			
RDRSYS	Common	Three-character radar system identifier			
SIGMA	Argument	Target RCS (m^2)			
TARRG	Argument	Actual range to target (m)			
TARAZ	Argument	Target azimuth from weapon system (rad)			
TAREL	Argument	Target elevation from weapon system (rad)			
TOTLOS	Common	Transmitter system losses			
WLNTH	Common	Radar transmit wavelength (m)			

TABLE 2.20-9. Subroutine RDREQT Input/Output Variables.

SUBROUTINE: RDREQT					
INPUTS			**OUTPUTS**		
NAME	**TYPE**	**DESCRIPTION**	**NAME**	**TYPE**	**DESCRIPTION**
COSP2	Argument	Cosine of the multipath phase angle shift, single-bounce path	**RDREQT**	Function	Track radar signal return power from target, includes multipath (W)
COS2P2	Argument	Cosine of the multipath phase angle shift, double-bounce path			
ECHO	Common	Radar signal return power from target, no multipath contributions (W)			
FACTOR	Common	Loss factor due to transmitter system losses			
GMPATH	Argument	Normalized antenna gain in the direction of the multipath reflection point			
GTARG	Argument	Normalized antenna gain in the target direction			
SIGMA	Argument	Target RCS (m^2)			
TARRG	Argument	Actual range to target (m)			

TABLE 2.20-10. Subroutine SIGJAM Input/Output Variables.

SUBROUTINE: SIGJAM					
INPUTS			OUTPUTS		
NAME	TYPE	DESCRIPTION	NAME	TYPE	DESCRIPTION
BEAM	Argument	Unit vector along beam axis (m)	JAMFAC	Argument	Antenna gain in direction of jammer (not normalized)
GANT	Common	Radar boresight antenna gain, not normalized			
JAMTYP	Common	Three-character jammer technique identifier			
JXLOC	Common	Jammer location coordinates (m)			
NUMJAM	Common	Total number of jammers			
RDRSYS	Common	Three-character radar system identifier			

2.20.4 Assumptions and Limitations

The following are the assumptions and limitations associated with the modeling of antenna gain in RADGUNS for the applicable system.

1. The antenna gain is assumed to be radially symmetrical.
2. The radar antenna and the object of interest are assumed to be separated by a distance sufficient such that the beam rays are parallel (a far-field condition is assumed).
3. The antenna gain is assumed to have a constant structure, and thus is independent of the target distance from the radar; this assumption is based on the satisfaction of Assumption 2.